Performance Analysis of a Novel Flexible NFC Tag for IoT Applications

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Abstract

This work reports on the simulations, analysis and measurements of a passive near field communication (NFC) tag antenna, and investigates the impact of the interconnect conductivity on its performance characteristics. Recently, flexible wearable devices and sensors are in great demand in healthcare applications [1]. Flexible NFC devices can be developed by employing novel interconnect materials such as polymer-metal composites [2]. However, these materials have a comparatively lower conductivity than conventional metals such as copper and silver [3]. The effect of interconnect conductivity on the performance of an NFC tag antenna through electromagnetic simulations and experimental measurements are presented.

Introduction

A passive NFC tag operates at 13.56 MHz, and harvests energy from the reader antenna through electromagnetic coupling [4]. In Fig.1 (a and b), a reader antenna and the equivalent circuit model for the NFC tag antenna is shown. The reader is a simple loop with capacitance C_R and inductance L_R, and is fed at Port 1. The equivalent circuit model of the inductively coupled NFC antenna can be represented by a tag inductance (L_T), tag capacitance (C_T) and a variable tag resistance (R_T), as shown in Fig.1 (b) [5].

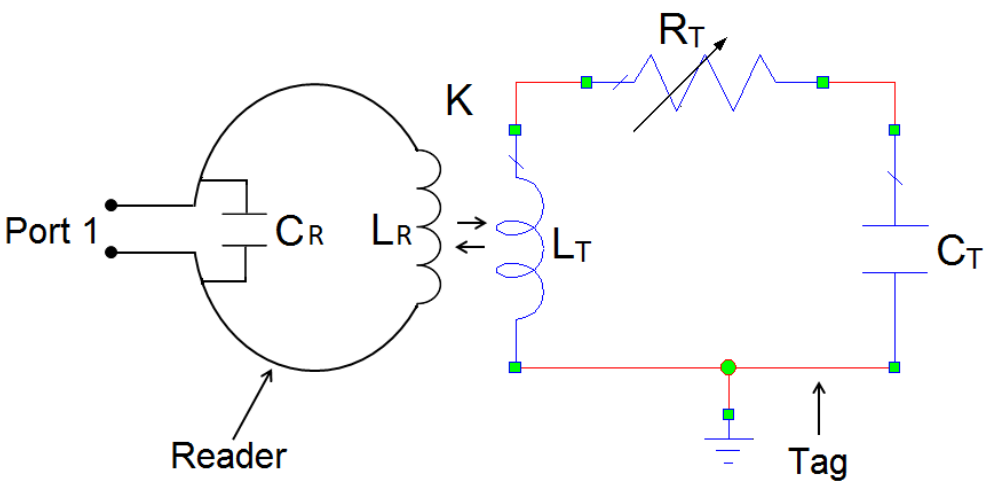


Fig. 1: (a) Reader antenna, (b) Equivalent circuit model of the NFC tag

Resistance R_T changes with variation in interconnect conductivity and is an important parameter that determines the maximum achievable read range, and the operational limit of the NFC tag antenna [6]. Coupling coefficient (K) governs the amount of radio frequency (RF) energy transfer between the reader antenna and the tag antenna [7]. The conductivity of the interconnect limits the performance of an NFC antenna, and below a certain conductivity limit, the NFC tag stops to respond to the reader antenna.

Antenna Design and Results

A simple bandage-like NFC tag antenna printed on low-cost FR4 substrate with dielectric constant 4.4, loss tangent 0.02, and the substrate thickness of 0.2 mm was investigated. As shown in Fig. 2, the overall dimension of the tag is L x W mm^2, where length (L) is 70 mm and width (W) is 20 mm. The width and thickness of the conductive trace is 0.5 mm and 0.035 mm respectively, and the gap between consecutive traces is 0.5 mm. The antenna is fed at the lumped port as shown in Fig.2.

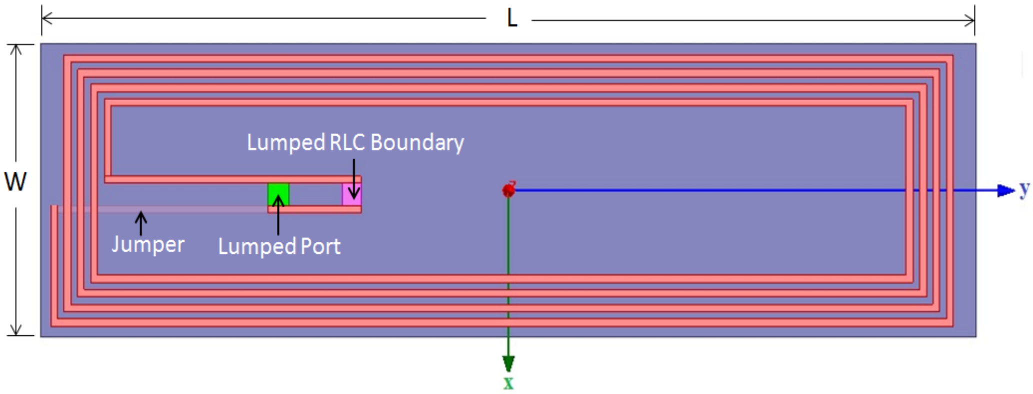


Fig. 2: Geometry of the bandage-like NFC tag antenna

The NFC tag antenna was simulated using Ansys HFSS full-wave commercial electromagnetic simulator [8]. To achieve the resonance at 13.56 MHz, a lumped RLC boundary condition was defined as, shown in Fig. 2. For a 4-turn NFC tag, the values of R, L and tuned C at 13.56 MHz were obtained as 50 Ω, 1.36 μH and 215 pF, respectively. For a comparative analysis, the tag antenna was simulated for two types of interconnects; copper and graphitic carbon. The sheet resistance of copper is 0.5 mΩ/□ and that of the graphitic carbon is 50 Ω/□ i.e. compared to copper, graphitic carbon is highly resistive in nature. The resistance corresponding to a 4-turn NFC tag was 0.65 Ω for copper and 48.6 KΩ graphitic carbon. The simulated antenna reflection coefficient (S_{11}) in the range of 6 - 20 MHz is shown in Fig.3. It can be seen that for copper (σ_{Cu} = 5.97 x 10^7 S/m), the antenna is resonant at 13.56 MHz with a good impedance matching.

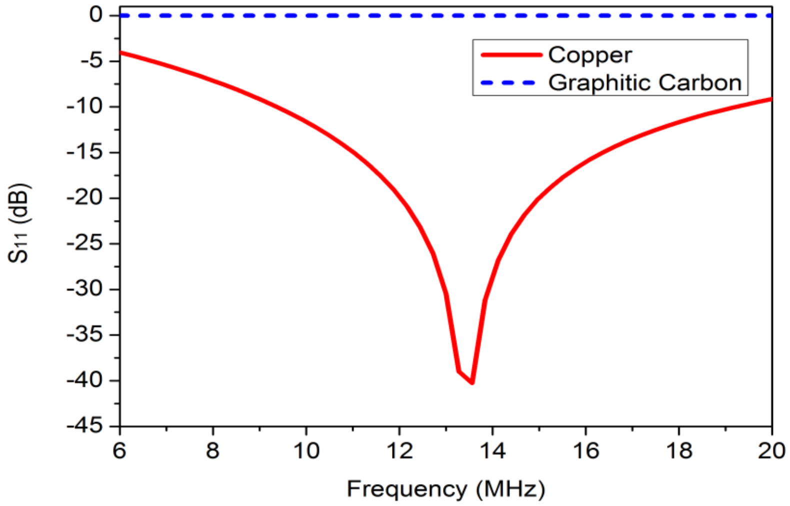
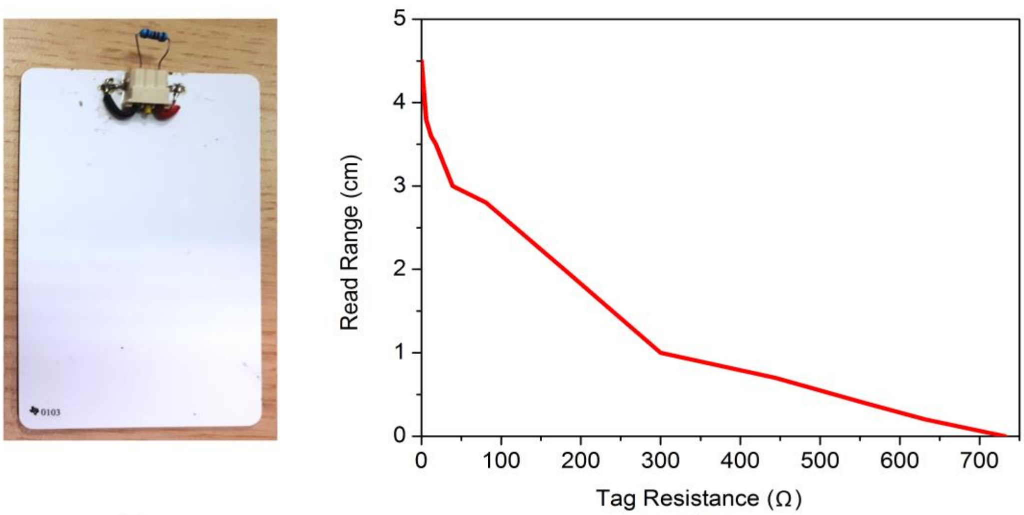


Fig. 3: Simulated return loss for copper and graphitic carbon interconnects

On the other hand, for graphitic carbon material (σ_{gc} = 800 S/m), the antenna is neither matched nor resonant at 13.56 MHz, owing to the large resistivity of the graphitic carbon interconnect material.

Further, to validate the dependence of NFC read range on the value of the tag resistance, an experiment was performed. In the experiment, the resistance of an NFC card, as shown in Fig. 4 (a) was varied in the range of 0 Ω to 800 Ω. The obtained read range is illustrated in Fig. 4 (b). For a small value of the tag resistance (~0 Ω), the read range is maximum, which is close to 4.5 cm. The read range decreases continuously with increase in the tag resistance, and for R_T equals to 732 Ω, the read range approaches 0 cm. i.e. NFC tag stops responding to the reader antenna. As the resistance for a 4-turn graphitic carbon tag is 48.6 KΩ (much higher than 732 Ω), the tag made of graphitic carbon is not suitable for the design of NFC antennas.



(a) (b)

Fig. 4: (a) NFC card for experiment (b) Read range versus tag resistance plot

Conclusion

The effect of interconnect conductivity on the performance characteristics of an NFC tag antenna is presented. Tag antenna performance was analysed for copper and graphitic carbon. Simulation and experimental results show that the tag resistance is an important parameter which determines the read range and optimal performance of the NFC system. It was concluded that the graphitic carbon is highly resistive and is not suitable for antenna applications.

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